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STRENGTH AND DUCTILITY OF THE COPPER-TIN-ZINC ALLOYS.

By ROBERT H. THURSTON, Member of the Society.

PRESENTED AT THE 13TH ANNUAL CONVENTION, JUNE 17TH, 1881.

In a paper read before the American Society of Civil Engineers a few months since,* the writer gave an account of a method of research which led to the approximate determination of the composition of the strongest possible triple alloy of copper-tin-zinc, and described the properties of alloys made with more or less accuracy and care by the formula of com-

* "THE STRONGEST OF THE BRONZES." Trans. Am. Soc. C. E. No. CCXIV.; Vol. X.; Jan., 1881.

position so obtained. In order to exhibit the relation of such metals to the other triple alloys, some of which were already well known compositions, a sketch was given of the relief model used in the identification of the strongest possible metal obtainable by mixture of the three constituents, and a map exhibiting lines of equal tenacity as derived by admeasurements of this model was also introduced as presenting the tenacity of the alloys with greater exactness. This map is here reproduced with some modifications (Fig. 1), which are demanded in further study of the characteristics of these alloys. It was remarked in the earlier paper:

"These alloys were purposely made precisely as the brass-founder is accustomed to make them, without other precautions than those observed by every good founder, and without using any of the deoxidizing fluxes—as phosphorus—that would have been experimented with later. The intention was to make this first survey of the field rapidly, inexpensively, and in such a manner as to give a good idea of the best way to pursue the later and much more exact research, while giving the founder a good idea of the nature of the metals that he turns out in every day work.

"The data obtained were consequently exceedingly variable, and the results of this work indicated as one, and not the least valuable, of deductions from it that the same alloy, and especially where the proportion of copper is great, may give very different figures, when tested, according as it is more or less affected by the many circumstances that influence the value of all brass-foundry products.

"Some of the variations in the model are probably due to such accidental circumstances, and quality shown by any individual alloy is representative of a mean which the writer was often compelled to deduce from observations which were quite discrepant. But allowing for all such minor variations, it is evident at a glance that the alloys of maximum strength are grouped, as shown in Figures 3 and 4, about a point not far from copper = 55, zinc = 43, tin = 2. This point is encircled in the map, Figure 3, by the line marked 65 000 pounds per square inch (4 570 kilogs. per sq. cm.) tenacity, and is represented on the model by the peak of the mountain seen at the farthest side—the copper-zinc side as drawn.

"This is obviously the strongest of all bronzes, and an alloy of this composition, if exactly proportioned, well melted, perfectly fluxed, and so

poured as to produce sound and pure metallic alloy, with such prompt cooling as shall prevent liquidation, is the strongest bronze that man can make."

This alloy and the "Tobin alloy"—copper, 58.22; tin, 2.30; zinc, 39.48—were described as good working metals, having toughness and some ductility as well as great strength, and the latter as being capable of great improvement by skillful working either hot or cold, and thus of attaining a tenacity of over 100 000 pounds per square inch (7 311 kilogs. per sq. cm.). Following the inequalities exhibited by the map, the writer called attention to the fact that a line of maximum elevation crosses the field from about: copper, 50; zinc, 50; to copper, 85, tin, 15, is included in a band bounded by the formulas: $M = Z + 4t = 50$, and $M = Z + 3t = 55$, in which Z is the percentage of zinc present in any triple alloy of that series, and T is the percentage of tin. It was stated that along this maximum line the tenacities of the alloys should be at least $T_m = 40\,000 + 500z$ in pounds on the square inch, or $T^1{}_m = 2\,812 + 35.15z$ in kilograms on the square centimeter. Thus taking the last line which contains the strongest but least ductile compositions, we find the following tenacities:

The alloy $z = 1$, $t = 18$ will also contain copper $= 100 - 19 = 81$ and this alloy cu. 81, zn. 1, sn. 18 should have a tenacity of at least

$$T_m = 40\,000 + (500 \times 1) = 40\,500 \text{ lbs. per sq. in.}$$
$$T^1{}_m = 2\,812 + (35\,15 \times 1) = 2\,847 \text{ kgs. per sq. cm.}$$

The alloy: cu. 60; zn. 5; sn. 16; should have at least the strength

$$T_m = 40\,000 + (500 \times 5) = 42\,500 \text{ lbs. per sq. in.}$$
$$T^1{}_m = 2\,812 + (35.15 \times 5) = 2\,988 \text{ kgs. per sq. cm.}$$

while the alloy z, 50; sn, 2; cu, 48; should give, as a minimum per specification:

$$T_m = 40\,000 + (500 \times 50) = 65\,000 \text{ lbs. per sq. in.}$$
$$T^1{}_m = 2\,812 + (35.15 \times 50) = 4\,570 \text{ kgs. per sq. cm.}$$

"These are rough working formulas that, while often departed from in fact, and while purely empirical, may prove of real value in framing specifications. The formula for the value of T_m fails with alloys containing less than 1 *per cent. tin* as the strength then rapidly falls to $t = 0$."

The writer does not recommend these alloys of maximum tenacity for all purposes of construction, as many of them, especially those near the tin side, are too deficient in ductility and resilience to be safely used where likely to be exposed to severe shock. Where the composition is that of brass, rather than bronze, this line of alloys exhibits more toughness. The alloys—copper, 55; tin, 2; zinc, 43; and copper, 55, tin, 0.5;* zinc, 44.5—were quite excellent in this particular. Tin reduces ductility more rapidly than does zinc. Alloys on the copper side of $z + 4t = 40$ are all tough metals. The copper tin alloys or bronzes, as was stated, should have a tenacity of at least: $T_t = 30\,000 + 1\,000t$ where containing not more than about 15 per cent. tin, or in metric measure, $T'_t = 2\,109 + 70.3\,t$, while the brasses or copper-zinc alloys up to 50 per cent. zinc should have a strength, in British and metric units respectively, of $T_z = 30\,000 + 500z$ and $T'_z = 2\,109 + 35.15z$. Thus gun bronze can be given about $30\,000 + (1\,000 \times 10) = 40\,000$ lbs. per square inch if well made. In metric measures, $2\,109 + 703 = 2\,812$ kilogs. per sq. cm. Copper, 70; zinc, 30, should have a tenacity of $30\,000 + (500 \times 30) = 45\,000$ lbs. on the square inch, or $2\,109 + (35.15 \times 30) = 3\,165$ kilogs. per square centimeter. Comparing the last two formulas for tenacity, it is seen that they may be combined giving equations covering the whole field of copper-tin-zinc alloys useful to the engineer, thus:

$$T_{tz} = 30\,000 + 1\,000\,t + 500z.$$
$$T'_{tz} = 2\,109 + 70.3\,t + 35.15z.$$

But it must be understood that this approximate statement of tenacities is a minimum for well made alloys, and is also applicable only to those containing a larger percentage of copper than to those which lie along the maximum line; the alloys to which they apply are, however, the best alloys for general use. Like all such formulations, they must be taken with reserve, and as only representing the cases from the study of which they were derived. For all ordinary purposes of the engineer they may be used without hesitation. Thus we get, for alloys in which $z + 4t < 40$, the following tenacities, representing the minimum that should be accepted; these figures may be greatly exceeded:

* Not 2.5, as printed in the earlier paper.

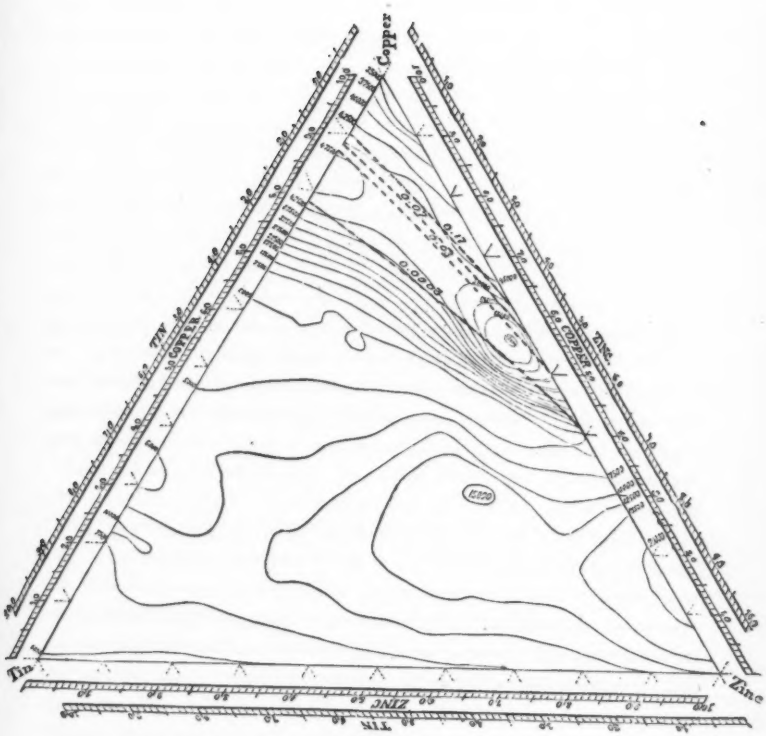


FIG. 1.

Alloy.			Tenacity—Probable Minimum.	
Cu.	Zn.	Sn.	Lbs. per sq. in.	Kgs. per sq. cm.
100	0	0	30 000	2 109
95	5	0	32 500	2 285
90	10	0	35 000	2 460
85	15	0	37 500	2 636
90	0	10	40 000	2 812
95	0	5	35 000	2 460
97½	0	2½	32 500	2 285
90	5	5	37 500	2 636
85	10	5	40 000	2 812
75	20	5	45 000	3 163
68	30	2	47 000	3 304
64	35	1	48 500	3 410
60	40	0	50 000	3 515

The ductility of these alloys is a subject of quite as much interest to the engineer as their strength; and in this quality the triple alloys are as variable as in every other. Referring again to the map, Figure 1, it is seen that a closely grouped set of slightly curved and slowly converging lines cross it from about tin = 25 to zinc = 55, the mean line having an equation, nearly $2.2t + z = 55$. Along this line the alloys have an immense tenacity as exhibited by the fact that some of them, if not nearly all, are too hard to be cut by steel tools, and in shaping them only grinding tools—either the emery wheel or the grindstone—could be used, and even then with most unsatisfactory results. Yet such was the brittleness of these metals that no reliable test of their strength could be obtained. Even the slow and cautious handling possible in the autographic machine was quite inadequate to the production of regular and satisfactory determinations. The strain diagrams obtained were perfectly straight, and nearly vertical lines terminating suddenly when the piece snapped without the slightest indication of approach to an elastic limit. They were apparently perfectly elastic up to the point of fracture, but were so nearly destitute of resilience that no use can probably be made of them. Their brittleness was such that they would often break in the mould by their own contraction in cooling, although cast in a straight bar one inch (2.5 c. m.) thick and less than 30 inches (75 c. m.) long. In some cases they were cracked by the heat of the hand, and in several instances were

broken at the end by the jar transmitted from a light blow struck at the other end.*

The border lines of this valueless territory is shown on the map by a slightly curved dotted line to which a line having the equation $2.5t + z = 55$ is nearly tangent. The alloys lying along this line have nearly equal ductility, extending according to the measurements obtained by the autographic machine, about .03 of one per cent.

Above this line is seen another having nearly the equation $4t + z = 50$, which last line is that of equal ductility for alloys exhibiting extensions on the strain diagram of 3 per cent. Still nearer the "pure copper corner" fairly representing alloys containing about $3\frac{1}{2}t + z = 48$, and along which the extensions, as per strain diagrams were 7.3 per cent., and another such line extending from the standard gun-metal compositions on the one side to the tough Muntz metal on the other—cu. 90 ; sn. 10 ; to cu. 55 ; zn. 45 ;—of which the equation is nearly $4.5t + z = 45$, represents and identifies alloys averaging as cast during this initial research, an extension of 17 per cent. These lines are best seen on the sheet of extensions, Fig. 2. All alloys lying above the line taken here as a boundary line give figures for tenacity that are usually considered good ; they all exceed 30 000 pounds per square inch (2 109 kilogs. per sq. cm.).

It is seen that the addition of tin and of zinc to cast copper increases tenacity at least up to a limit marked by the line $3t + z = 55$, and that the influence of tin is nearly twice as great as that of zinc, while the limit of useful effect is not reached in the latter case until the amount added becomes very much greater than with the former class—the copper-tin alloys.

Brasses can be obtained which are stronger than any bronzes, and the ductility of the working compositions of the former class generally greatly exceeds that of the latter.

Triple alloys may be made containing about $4t + z = 50$, which exceed in strength any of the double alloys and compositions approaching copper, 55 ; tin, 2 ; zinc, 43 ; as the maximum of maximums, may be made, which are of extraordinary value for purposes demanding great strength, combined with the peculiar advantages offered by brass or bronze. The addition of one-half per cent. tin to Muntz metal confers vastly increased strength. So sensitive is zinc to the presence of tin that M. Bischof

* Report of United States Board,

states that he can detect the addition of one part of tin in ten millions of pure zinc.

The range of useful introduction of tin is very much more restricted than with zinc; alloys containing 12 to 15 per cent. tin are so hard and brittle as to but rarely find application in the arts, while brass, containing 40 per cent. zinc, is about the toughest and most generally useful of all the copper-zinc "mixtures." The moduli of elasticity of these alloys are remarkably uniform, more than one-half of all those here described, ranging closely up to fourteen millions, or one-half that of well made steel-wire, such as is used in the New York and Brooklyn Bridge. The moduli gradually and slowly increase from the beginning of the test to the elastic limit.

The fracture of these alloys is always illustrative of their special characteristics. Those broken by tortion in the autographic testing machine were, if brittle, more or less conoidal at one side of the break; ductile alloys yield in similar circumstances by shearing in a plane at right angles to the axis of the test piece; the former resemble cast iron and the latter have the fracture of wrought iron. Every shade of gradation in this respect is exhibited by an observable modification of the surface of fracture varying from that characteristic of extreme rigidity and brittleness, through an interesting variety of intermediate and compound forms to that seen in fracture of the most ductile metals.

Notwithstanding the fact that the demise of the United States Board left this investigation in a sadly incomplete state, it will probably become evident to those who may obtain the report that at least a beginning has been made and the field fairly reconnoitred, leaving to some future investigator a prospect of immediate valuable recompense for such additionable labor as he may be able to expend in a detailed reconnoissance or an extended survey. While studying the figures here given, and especially those reported by the United States Board, it must not be forgotten that the tenacities and even the ductilities given are far within the best attainable figures where they relate to the most valuable working bronzes and brasses. These figures represent the result of ordinary, every day founders' work, and metals rich in copper made, as were these, with no greater precaution against oxidation and liquation than is usual in brass foundries, may be vastly improved by the special treatment suggested in the preceding paper—by using pure ingot metals, fluxing carefully, as with phosphorous or manganese, casting in chills, rapid

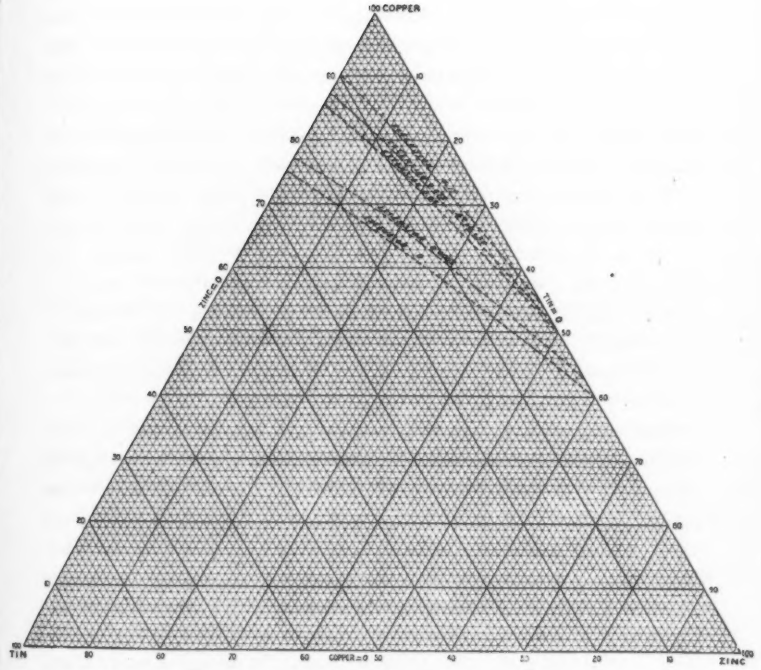


FIG. 2.

cooling, and finally rolling or otherwise compressing either hot or cold.

Unannealed copper wire is reported by Baudrimont* as having a tenacity of about 45 000 pounds per square inch (3 163 kilogs. per sq. c. m.), and Kirkaldy reports 28.2 tons per square inch (63 168 pounds per square inch; 4 440 kilogs. per square c. m.), the wires having diameters of 0.0177 and 0.064. inches (0.044 and 0.165 c. m.) respectively.

It can hardly be doubted that a way may yet be found to secure equal purity, homogeneousness and density in cast copper, and such metal should then possess equal tenacity and toughness with rolled metal. Gun-bronze, which ordinarily has a tenacity of about 35 000 pounds per square inch (2 460 kilogs. per sq. cm.) has been made at the Washington Navy Yard, by skillful mixture, melting and pouring, to attain a tenacity of above 60 000 pounds (4 218 kilogs.).

The effect of thorough fluxing with deoxidizing substances is so important that no founder can safely neglect it.

Bronzes fluxed with phosphorus, arsenic, and manganese have been given fifty per cent. higher tenacity than the ordinary unfluxed alloy, and the addition of a little iron, as in the so-called "sterro-metal" of the Baron de Rosthorn, and in Parson's "Manganese Bronze," has still further strengthened the copper-tin-zinc alloys.

Attention has been called in the preceding paper to the value of cold rolling, and other mechanical treatment of the "maximum alloys," examined by the writer, and one case was cited in which the tenacity was increased from 66 500 pounds per inch (4 575 kilogs. per sq. cm.) by rolling hot to 79 000 pounds (5 553 kilogs.), and by cold rolling to 104 000 pounds (7 311 kilogs.). Dr. Anderson, the Superintendent of Machinery of the British War Department, when associated with the writer at Vienna, 1873, referred to experiments at Woolwich, showing an increase of strength of sterro-metal by forging to the extent of 25 per cent., and by drawing cold of 40 per cent. Brass, containing copper, 62 to70; zinc, 38 to 30, attains a strength in the wire mill of 90 000 pounds per square inch, and sometimes of 100 000 (6 327 to 7 030 kilogs. per sq. cm.), and the time will come, we may hope, and fairly expect, when these alloys may be made equally tenacious in the casting. The writer has no doubt that the methods indicated by him as those best adapted to secure dense, strong and tough

* Annales de Chimie, 1850.

metal will yet be found capable of yielding alloys of more than double the strength shown here to be fairly representative of what is now ordinary brass founder's work. It should be possible to secure copper-tin-zinc alloys having tenacities represented by :

$$T_{mm} = 60\,000 + 1\,000t + 500z,$$
$$T'_{mm} = 4\,218 + 70.3t + 35.15z,$$

throughout that area on the map representing the more useful alloys, say from copper, 100 ; to $4t + z = 50$.

Manufacturers of special bronzes are already approaching this degree of excellence. The appended tables illustrate the method of investigation adopted in studying the triple alloys, and exhibit the behavior under test of the sample of "Gun Bronze, No. 1 252," of which autographic strain diagrams were given in fac-simile in the preceding paper on "The Strongest of Bronzes." This bar was made to order for the writer to determine the value of an organic material proposed as a flux ; it had no special value, however, and the record is here given in illustration only.

No. 585 was a sample of brass in which 20 per cent. zinc takes the place of 10 per cent. tin in bar No. 1 252. This piece had very nearly the same tenacity, double the ductility, a slightly lower modulus of elasticity, and far less transverse strength—probably in consequence of less hardness. Adding zinc until the proportion becomes 37.5 per cent., as in No. 609, the tenacity rises to 48 760 pounds per square inch (3 428 kilogs. per sq. cm.), the modulus of elasticity is increased to fifteen millions, and the transverse strength is doubled.

No. 856 is an alloy of very nearly the same composition, to which 23 per cent. tin has been added. It is seen that this change has produced an enormous increase of strength, bringing the tenacity up to 67 600 pounds per square inch (4 752 kilogs. per sq. cm.), and while decreasing the modulus of elasticity has greatly increased the transverse strength. This bar was referred to in the preceding paper, and the records of its test are here also appended as exhibiting the behavior of this alloy during the progress of the tests. The extensions given are measured in a length of five inches ; they are, therefore, to be multiplied by 20 to obtain the percentage of extension. This bar is very strong, but deficient in ductility.

The transverse test exhibits these characteristics with equal distinctness. The load carried was nearly a ton and a half, and the deflection

but 2 inches (5 cm.); the modulus of elasticity slowly but steadily decreased from the start. Note (*a*) calls attention to a singular phenomenon more than once noticed, of an increased effort to decrease flexure after a short interval of rest under light load, having received set under heavier stress. The remainder of the record illustrates the usual gradual increase of set under heavy loads. Somewhat similar behavior was noticed in the transverse test of No. 1 001, an alloy of which the strain diagrams from the autographic machine were given in the paper on the strongest of the bronzes. The note appended to the record calls attention to this singular recovery from set, which here amounts to 0.004 inches (0.01 cm.) in about 16 hours.

The last set of records here given are those of a bar of pure copper, made and tested for the U. S. Board,* and show well what may be expected of good copper castings, even without special fluxing or other unusual treatment. This bar was strong, carrying nearly 30 000 pounds per square inch (21.09 kilogs. per sq. cm.) in tension, but it lacked ductility, a consequence of the presence of copper oxide.

In the working of copper in the foundry the melter is sure to meet with difficulty from the formation of either the oxide or carbide. Could he secure immunity from the danger of combination with one or the other of these elements, he would find innumerable uses for cast copper. One of the discoveries to be looked for, and to be hoped for, is a method of securing pure cast copper. The stronger affinities of the metal, when molten, make this problem a more difficult one than that of obtaining sound steel castings. The transverse strength of the metal seemed to have been less reduced by the presence of the oxide than was its tenacity. The fact that the bar could be broken at all in the transverse testing machine is evidence of reduction of ductility due to this cause. The record of the compression test seems to indicate that form of resistance due to the presence of oxide.

The general character and the method of variation of strength and ductility of the alloys of copper, tin and zinc are so well exhibited by the illustrations which have been presented in these papers, that it is the hope of the writer that no difficulty will be met with by the engineer in the endeavor to select the alloy best adapted to any specific purpose where such an adaptation is determined by physical qualities alone.

*See Report of 1878.

Caution must be used in selecting alloys where great strength is demanded, since a slight change of composition by the addition of tin or zinc may make a serious change in the direction of lessened ductility and toughness. The engineer will rarely use those lying on the tin and zinc side of the line of alloys having 0.07 (7 per cent.) ductility, as on Figs. 1 and 2. Extraordinary care must also be taken in making the strongest of these alloys.

Alloys to be hammered or rolled will be found more difficult to work as the percentage of tin is increased, and the minutest addition of tin to the brasses usually rolled is found to sensibly decrease their manageability.

RECORDS OF TESTS MADE AT THE

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING,

Stevens Institute of Technology.

Material, Bronze :
Copper.....89,974%
Tin..... 9,997%
Flux, &c..... 0,029%

1. RECORD ACCOMPANYING AUTOGRAPHIC STRAIN DIAGRAMS.

GUN BRONZE.

LAB. No.	SIZE FOR ESTIMATES.		STRESSES IN TORSION. FOOT-POUNDS.		Elasticity.	Elastic Resilience.	RATIO OF EXTENSION.		HOMOGENEOUSNESS AS TO		Stiffness.	Resilience. W	MODULUS OF RESISTANCE TORSION. (A)			ANGLE.	
	Length. L	Diameter. H	Proof. M'	Ultimate. M			Proof.	Maximum.	Structure.	Strain.			Elastic. $A_E = \frac{M'L}{H^5 \Theta_E}$	Proof. $A' = \frac{M'}{H_3}$	Ultimate $A = \frac{M}{H_3}$	Θ_E	Θ_R
1252B	1"	.625"	49.03	99.83	.00717	0.38	.000013	.04737	Ex.	Ex	54.5	84.60	571.2	200.94	409.1	0.9°	57.2
$1252B_2$	"	"	71.71	127.05	.00776	1.55	.000089	.07554	"	"	29.9	138.66	313.3	293.9	520.7	2.4°	72.6

2. RECORDS OF TESTS BY TENSION.

Copper.. . 89.974%
Tin..... 9.997% GUN BRONZE.
Flux, &c.. 0.029% Lab. No. 1252A²

DIMENSIONS. ORIGINAL AND FINAL.		STRESSES.		PROOF LOAD PER SQUARE INCH AREA OF	BREAKING LOAD PER SQUARE INCH.	EXTENSION.			
Length. L, L′	Diameter. H, H′	Proof.	Ultimate.	Original Section. P	Original Section. T	Actual.	% of Original Length.	Modulus of Elasticity. E	Modulus of Resilience. W
5″	.798″	150	.....	300	.....	.....	.....	11 467 763	
.....	.....	1000	.....	2000	.....	.0008	.016%		
.....	.....	2000	.....	4000	.....	.0016	.03		
.....	.....	3000	.....	6000	.....	.0024	.05		
.....	.....	4000	.....	8000	.....	.0036	.07		
Elastic	Limit.	5000	.....	10000	.....	.0047	.09	.....	0.98
.....	.....	6000	.....	12000	.....	.0063	.13		
.....	.....	7000	.....	14000	.....	.0080	.16		
.....	.....	8000	.....	16000	.....	.0112	.22		
.....	.....	9000	.....	18000	.....	.0166	.33		
.....	.....	10000	.....	20000	.....	.0263	0.53		
.....	.....	11000	.....	22000	.....	.0428	.86		
.....	.....	12000	.....	24000	.....	.0675	1.35		
.....	.....	13000	.....	26000	.....	.1009	2.045		
.....	.....	15000	.....	30000	.....	.2069	4.14		
.....	.....	.....	15500	.....	31000	.23	4.6	.....	242

3. RECORDS OF TESTS BY COMPRESSION.

Copper..... 89.974%
Tin..... 9.997% GUN BRONZE.
Flux, &c..... 0.029% Lab. No. $1252C_2$.

DIMENSIONS, ORIGINAL AND FINAL.		STRESSES.	PROOF LOAD PER SQUARE INCH AREA OF	BREAKING LOAD PER SQUARE INCH.	COMPRESSION.		RESILIENCE. W
Length. L, L′	Diameter. H, H′	Proof.	Original Section. P	Original Section. T	Actual.	% of Original Length.	Foot-Pounds.
2"	.625	150					
		1000			0.0019"	0.09%	
		2000			.0032	.16	
		3000			.0033	.16	
		4000			.0040	.20	
		5000			.0048	.24	
		6000			.0076	.38	
Elastic	Limit.	7000	22816		.0117	.58	6.825
		8000			.0227	1.13	
		9000			.0385	1.92	
		10000			.0609	3.04	
		11000			.0867	4.33	
		12000			.1163	5.81	
		13000			.1494	7.47	
		14000			.1794	8.97	
		15000			.2110	10.55	
		16000			.2402	12.01	
		17000			.2678	13.39	
		18000			.2989	14.94	
		19000			.3229	16.14	
		20000			.03599	17.99	
		21000			.3904	19.52	
		22000			.4164	20.82	
		23000			.4478	22.39	
		24000			.4870	24.35	
		25000			.5092	25.46	
		26000			.5409	27.04	
		27000			.5706	28.53	
		28000			.5999	29.99	
		29000			.6235	31.17	
		30000			.6460	32.30	
		31000			.6694	33.47	
		32000			.6904	34.52	
		33000			.7125	35.62	
		34000			.7311	36.55	
		35000			.7517	37.58	
		36000			.7726	38.63	
		37000			.7914	39.57	
	.769	38000		123860	.8115	40.57	1.480

4. RECORDS OF TESTS BY TRANSVERSE STRESS.

Copper... 89.974%
Tin ... 9.997%
Flux, &c... 0.029%

GUN BRONZE.

Lab. No. 1252.

DIMENSIONS Original and Final.		
Length.	Breadth.	Depth.
l. l'.	b b'.	d. d'.
22″	1.020″	0.97″

	PROOF STRESSES.		DEFLECTION.	BREAKING LOAD.		MODULUS OF ELASTICITY.	MODULUS OF RESILIENCE.
	Absolute. P'	Modulus. $R_1=\frac{3 P_1 l}{2 b d_2}$	Absolute. δ	Absolute. P	Modulus. $R=\frac{3 P l}{2 b d_2}$	$E=\frac{P l_3}{48 \delta 1}$	W Ft. Lbs.
	3	.... ..	.....	.....	.....	13 487 264	
	10	....	0.0016″				
	20	.....	.0036				
	40	.....	.0084				
	80	.....	.0179				
	120	.....	.0257				
	160	....	.0344				
	200	.....	.0429				
	3	.... ..	.0012				
	240	.....	.0502				
	280	.....	.0581				
	320	.....	.0669				
	360	.....	.0761				
	400	.....	.0845				
	3	.....	.0034				
	440	.....	.0929				
	480	... .	.1015				
	520	.....	.1102				
	560	.....	.1192				
	600	.....	.1277				
	3	.....	0.0054				
	640	.....	.1364				
Elastic Limit.	680	23 375	.1463	.....	.....	.....	4.145
	720	....	.1594				
	760	.....	.1717				
	800	.....	.1879				
	3	.....	.0276				
	840	....	.2039				
	880	.....	.2219				
	920	.....	.2475				
	960	.....	.2832				
	1000	.....	.3310				
	3	.....	.1248				
	1040	... .	.3841				
	1080	.....	.4426				
	1120	.....	.5359				

4. RECORDS OF TESTS BY TRANSVERSE STRESS.—*Continued.*

			Dimensions Original and Final.		
			Length.	Breadth.	Depth.
Copper....	89.974%	Gun Bronze.	$l.\ l'$	$b.\ b.'$	$d.\ d'.$
Tin.....	9.997%				
Flux, &c...	0.029%	Lab. No. 1252.	22″	1.020″	0.97″

	Proof Stresses.		Deflection.	Breaking Load.		Modulus of Elasticity.	Modulus of Resilience.
	Absolute. P_1	Modulus. $R_1=\frac{3\,P_1\,l}{2\,b\,d_2}$	Absolute. δ	Absolute. P	Modulus. $R=\frac{3\,P\,l}{2\,b\,d_2}$	$E=\frac{P\,l_3}{48\,\delta\,I}$	W Ft. Lbs.
	1160	.....	.6492″				
	1200	.....	.7774				
	3	.....	.5114				
	1240	.....	.9043				
	1280	.....	1.027				
	1320	.....	1.1998				
	1360	.....	1.407				
	1400	.....	1.694				
	3	.....	1.2008				
	1440	.....	1.835				
	1480	.....	2.020				
	1520	.....	2.237				
	1560	.....	2.553				
	1600	.....	3.1108				
	3	.....	2.462				
	1640	.....	3.358	1640	56 375	.....	327.5

5. RECORD OF TESTS BY TENSION.

Copper.. 80%
Zinc 20%

ALLOY OF COPPER AND ZINC.

Lab. No. 585B.

DIMENSIONS. Original and Final.	
Length. L, L′	Diameter. H, H′
5″	.798

STRESSES.		PROOF LOAD PER SQUARE INCH AREA OF		BREAKING LOAD PER SQUARE INCH.		EXTENSION.
Proof.	Ultimate.	Original Section. P	Fractured Section. P′	Original Section. T	Fractured Section. T′	Actual.
4800						.0018
5000						.0037
5200						.0075
5400						.0132
5600						.0205
6000						.0385
220						.0127
6400						.0622
6800						.0904
8000						.1849
8800						.2450
9600						.2979
10400						.3530
11200						.4495
11600						.4880
12000 (*a*)						
16750 (*b*)	16750	33140	55599	33140	55599	

(*a*.) Micrometer slipped, further reading of no value.
(*b*.) Total elongation, measured after breaking 1.62″

6. RECORD OF TESTS BY TRANSVERSE STRESS.

Copper....80%
Zinc.....20%

ALLOY OF COPPER AND ZINC.
Lab. No. 585

DIMENSIONS.		
Distance between Supports.	Breadth. b.	Depth d.
22"	.995	.985

PROOF STRESSES	DEFLECTION.	BREAKING LOAD.		MODULUS OF ELASTICITY.
Absolute. P_1	Actual.	Absolute. P	Modulus. $R=\frac{3Pl}{2db_2}$	$E=\frac{Pl_3}{48\delta I}$
10	.0042			
40	.0124			9030560
80	.0206			10708667
120	.0296			11349217
160	.0363			12339278
200	0449			12469814
3	.0056			
240	.0544			12530618
280	.0692			11327350
320	.0980			9141138
360	.1659			6074807
400	.3288			3405686
3	.2445			
400	.3352			
420	.4414			
440	.5885			
460	.7520			
480	.9590			
500	1.1763			1189949
520	1.5463			
540	1.6163			
560	1.86			
580	2.22			
600	2.62			
620(a)	3.27	620	21193	

(a.) Bent down without breaking ; bar removed.

Fracture, " Surface in character resembling No. 584, but less jagged." Color : brass yellow.

7. RECORD OF TESTS BY TENSION.

Copper.... 62.5% Alloy of Copper and Zinc.
Zinc..... 37.5% Lab. No. 609A.

Dimensions. Original and Final.		Stresses.		Proof Load per Square Inch Area of		Breaking Load per Square Inch.		Extension.
Length. L, L′	Diameter. H, H′	Proof.	Ultimate.	Original Section. P	Fractured Section. P′	Original Section. T	Fractured Section. T′	Actual.
5"	.798	500						.0003
		1000						.0007
		1500						.0010
		2000						.0016
		3000						.0024
		4000						.0037
		5000						.0052
		6000						.0066
		100						.0008
		7000						.0087
		8000						.0123
		100						.0047
		9000						.0185
		10000						.0447
		100						.0359
		11000						.0810
		12000						.1290
		100						.1162
		13000						.1782
		14000						.2375
		100						.2197
		15000						.3148
		16000						.3877
		100						.3650
		16500						.4334
		17500(*a*)						
	.670	24380(*b*)	24380	48760	68979	48760	68979	1.55"

(*a*). Micrometer slipped.

(*b*). Broke 2 inches from "C" end. Fracture; light brownish yellow, very compact, diagonal surfaces slightly polished. Several times during the test a dull sound was heard from the piece, and at the same instant the resistance decreased, in one instance to the extent of 1300 pounds.

8. RECORD OF TESTS BY TRANSVERSE STRESS.

Copper....62.5%
Zinc.....37.5%

ALLOY OF COPPER AND ZINC.

Lab. No. 608.

DIMENSIONS.		
Distance between Supports.	Breadth. b.	Depth. d.
22″	.970	.972

PROOF STRESSES.	DEFLECTION.	BREAKING LOAD.		MODULUS OF ELASTICITY.
Absolute. P_1	Actual.	Absolute. P	Modulus. $R=\frac{3Pl}{2bd_2}$	$E=\frac{Pl_3}{48\delta I}$
10	.0044	.... .	.....	
20	.0061	....	.....	
40	.0078	.....	.....	15325081
80	.0167	.... .	.....	14315643
120	.0244	.....	... ..	14697004
160	.0327	... ..	... ..	14622094
200	.0417	.... .	.....	14332809
3	.0040	... ..	.....	
240	.0506	.....	..	14174185
280	.0598	.....	.....	13992465
320	.0690	.....	... ..	13859204
360	.0775	.. ...	... ..	13881558
400	.0874	.....	.....	13677164
3	.0023	.....	.....	
440	.0958	.. ..	... ..	13757029
480	.1028	.....	.....	13953576
520	.1102	.....	.....	14101299
560	.1198	.....	.....	13969106
600	.1318	.....	.....	13604210
3	.0048	.....	.....	
640	.1493	.....	.....	12810242
680	.1630	.....	..	
720	.1832	.....	.....	11771840
760	.2130	.....	.. ...	
800	.2628	.....	.....	9097079
3	.0760	.....	.....	
840	.3160	.....	.....	
880	.4461	.....	.....	
920	.6000	.....	.....	4978218
960	.7782	.....	.....	
1000	.8927	.....	.....	3347588
3	.7277	.....	.....	
1040	1.1753	.....	... .	
1080	1.53	.....	.....	2109413
1120	1.88	.....	.....	
1160	2.23	.....	.....	
1200 (a)	3.13	1 200	43 216	1145709

(a) Bar bent down without breaking.

9. RECORD OF TESTS BY TENSION.

Triple Alloy of Copper, Tin and Zinc.

Copper.... 58.22%
Tin..... 2.30%
Zinc..... 39.48%

Tobin's Alloy.

Lab. No. 856B.

Dimensions. Original and Final.	
Length. L, L′	Diameter. H, H′
5″	.798

Stresses.		Breaking Load per Square Inch.		Extension.
Proof.	Ultimate.	Original Section. T	Fractured Section. T′	Actual.
150				.0
500				.0012
1000				.0022
1100				.0024
1200				.0026
1300				.0028
1400				.0030
1500				.0032
1600				.0034
1700				.0036
1800				.0038
1900				.0041
2000				.0044
2500				.0054
3000				.0064
3500				.0074
4000				.0081
4500				.0088
5000				.0095
150				.0022
5000				.0113
6000				.0125
7000				.0137
8000				.0150
9000				.0165
10000				.0176
11000				.0189
12000				.0202
13000				.0213
14000				.0226
15000				.0240
16000				.0254
17000				.0268
18000				.0282

9. RECORD OF TESTS BY TENSION.—(*Continued.*)

TRIPLE ALLOY OF COPPER, TIN AND ZINC.

Copper.... 58.22%
Tin..... 2.30%
Zinc..... 39.48%

TOBIN'S ALLOY.

Lab. No. 856B.

DIMENSIONS. Original and Final.	
Length. L, L′	Diameter. H, H′
5″	.798

STRESSES.		BREAKING LOAD PER SQUARE INCH.		EXTENSION.
Proof.	Ultimate.	Original Section. T	Fractured Section. T′	Actual.
19000				.0297
20000				.0313
150				.0150
5000				.0215
10000				.0279
15000				.0345
20000				.0399
21000				.0423
22000				.0447
23000				.0473
24000				.0494
25000				.0527
26000				.0568
27000				.0615
28000				.0674
29000				.0771
30000				.0873
31000				.0958
32000				.1277
33000				.1577
33800(*a*)	33800	67600	73160	

(*a*.) Broke. Fracture : yellowish gray, with light pinkish shade. Open granular structure, with a few very minute blow holes, several lustrous points scattered over the surface. No radiated lines were seen like those of the transverse fracture.

10. RECORD OF TESTS BY TRANSVERSE STRESS.

Triple Alloy of Copper, Tin and Zinc.		Dimensions.		
Copper. 58.22%		Distance between Supports.	Breadth. b.	Depth. d.
Tin 2.30%	Tobin's Alloy.			
Zinc....39.48%				
	Lab. No. 856.	22″	1.010	.992

Proof Stresses.	Deflection.	Breaking Load.		Modulus of Elasticity.
Absolute. P_1	Actual.	Absolute. P	Modulus. $R=\frac{3\,P\,l}{2\,b\,d_2}$	$E=\frac{P\,l_3}{48\,\delta\,I}$
3				
10	0.0024			
20	0.0046			11760504
40	0.0098			11040471
80	0.0202			11712635
120	0.296			10965874
160	0.418			10353743
200	0.0517			10643891
10	.0032			
3	.0011			
200	.0532			
240	.0612			10607511
280	.0712			10637306
320	.0802			10792679
360	.0908			10724336
400	.1000			10819661
10	.0027			
3	.0008			
400	.1010			
440	.1095			10869067
480	.1197			10846777
520	.1294			10869829
560	.1403			11578364
600	.1511			14321161
10	.0032			
3	.0015			
600	.1515			
640	.1629			10627046
680	.1740			10570934
720	.1846			10550048
760	.1944			10574771
800	.2038			10617922
10	.0043			
3	.0032			
800	.2028			
840	.2142			10607511
880	.2247			10593349
920	.2344			10616562

10. RECORD OF TESTS BY TRANSVERSE STRESS.—(*Continued.*)

Triple Alloy of Copper, Tin and Zinc.		Dimensions.		
Copper. 58.22%		Distance between Supports.	Breadth. *b.*	Depth. *d.*
Tin 2.30%	Tobin's Alloy.			
Zinc.... 39.48%				
	Lab. No. 856.	22″	1.010	.992

Proof Stresses.	Deflection.	Breaking Load.		Modulus of Elasticity.
Absolute. P_1	Actual.	Absolute. P	Modulus. $R=\frac{3\,P\,l}{2b\,d_2}$	$E=\frac{P\,l_3}{48\,\delta\,I}$
960	.2433	.....	....	10672909
1000	.2550	.....	.....	10607511
10	.0064			
3	.0046			
1000	.2544			
1040	.2642	.....	.....	10647661
1080	.2764	.....	.....	10569132
1120	.2847	.....	.....	10641044
1160	.2951	....	.....	10632674
1200	.3062	.....	.....	10600509
10	.0114			
3	.0093			
1194*	.3069			
1240	.3170			
1280	.3276			
1320	.3398			
1360	.3528			
1400	.3673	.....	.....	10310049
10	.0210			
3	.0193			
1400	.3695			
1440	.3817			
1480	.3959			
1520	.4102			
1560	.4236			
1600	.4395	....	.....	9847245
10	.0407			
3	.0387			
1600	.4405			
1640	.4537			
1680	.4704			
1720	.4882			
1760	.5042			
1800	.5205	.....	.....	9354174
10	.0743			
3	.0727			

* After 55 minutes resistance decreased from 1200 to 1194 pounds.

10. RECORD OF TESTS BY TRANSVERSE STRESS.—(*Continued.*)

TRIPLE ALLOY OF COPPER, TIN AND ZINC.

Copper.58.22%
Tin.... 2.30%
Zinc....39.48%

TOBIN'S ALLOY.

Lab. No. 856.

DIMENSIONS.		
Distance between Supports.	Breadth. b.	Depth. d.
22″	1.010	.992

PROOF STRESSES.	DEFLECTION.	BREAKING LOAD.		MODULUS OF ELASTICITY.
Absolute. P_1	Actual.	Absolute. P	Modulus. $R = \frac{3 P l}{2 b d_2}$	$E = \frac{P l_3}{48 \delta I}$
1800	.5230			
1840	.5383			
1880	.5586			
1920	.5823			
1960	.6076			
2000	.6343			
10	.1340			
3	.1326			
8 (*a*)				
3	.1320			
2000	.6390	.....	.....	8955262
2040	.6594			
2080	.6856			
2120	.7140			
2160	.7456			
2200	.7777	.....	.....	7651812
2240	.8106			
2280	.8621			
2272 (*b*)	.8621			
2268 (*c*)	.8621			
2260 (*d*)	.8621			
2256 (*e*)	.8621			
2288 (*f*)	.8665 (*f*)			
2290	.8658			
2300	.8722			
2310	.8763			
2320 (*g*)	.8843 (*g*)			
2312 (*h*)	.8843			
2309 (*i*)	.8843			

(*a*) After 10 minutes resistance increased from 3 to 8 pounds.
(*b*) " 1 " " decreased " 2280 " 2272 "
(*c*) " 3 " " " " " " 2268 "
(*d*) " 25 " " " " " " 2260 "
(*e*) " 60 " " " " " " 2256 "
(*f*) to (*g*) presents slight elevation of Elastic Limit.
(*h*) Resistance decreased in 3 minutes from 2320 to 2312 pounds.
(*i*) " " " 10 " " " " 2309 "

10. RECORD OF TESTS BY TRANSVERSE STRESS.—(*Continued.*)

Triple Alloy of Copper, Tin and Zinc.		Dimensions.		
Copper. 58.22%		Distance between Supports.	Breadth. *b.*	Depth. *d.*
Tin.... 2.30%	Tobin's Alloy.			
Zinc. ..39.48%				
	Lab. No. 856.	22″	1.010	.992

Proof Stresses.	Deflection.	Breaking Load.		Modulus of Elasticity.
Absolute. P_1	Actual.	Absolute. P	Modulus. $R=\frac{3\ P\ l}{2\ b\ d_2}$	$E=\frac{P\ l_3}{48\ \delta\ I}$
2260 (*j*)	8770 (*k*)			
2270	.8867			
2280	.8893			
2290	.8919			
2300	.8948			
2310	.8967			
2320	.8990			
2330	.9019			
2340	.9063			
2350	.9165			
2342 (*l*)	.9165			
2350	.9189			
2360	.9239			
2370	.9418			
2380	.9529			
2390	.9650			
2400	.9764			
2410	.9888			
2420	1.0048			
2430	1.0189			
2440	1.0333			
2450	1.0438			
2460	1 0553			
2470	1 0755			
2480	1.0865			
2490	1 1013			
2500	1.1265			
2510	1.1341			
2520	1.1475			
2530	1.1647			
2540	1.1818			
2550	1.1918			
2560	1 2073			

(*j*) Resistance decreased in 66 hours 13 minutes from 2320 to 2260 pounds.

(*k*) Reading of extension apparatus changed, so as to correspond to deflection of 8770—probably caused by gradual set of machine under the constant strain, and compression or bending of the lower transverse timber.

(*l*) Resistance decreased in ten minutes from 2350 to 2342 pounds.

10. RECORD OF TESTS BY TRANSVERSE STRESS.—(*Continued.*)

Triple Alloy of Copper, Tin and Zinc.		Dimensions.		
Copper.58.22%		Distance between Supports.	Breadth. *b.*	Depth. *d.*
Tin 9.30%	Tobin's Alloy.			
Zinc....39.48%				
	Lab. No. 856.	22"	1.010	.992

Proof Stresses.	Deflection.	Breaking Load.		Modulus of Elasticity.
Absolute. P_1	Actual.	Absolute. P	Modulus. $R=\frac{3\ P\ l}{2\ b\ d_2}$	$E=\frac{P\ l_3}{48\ \delta\ I}$
2570	1.2293			
2580	1.2445			
2590	1.2585			
2600	1.2851	....	.....	5472552
2610	1.3063			
2620	1.3288			
2630	1.3406			
2640	1.3556			
2650	1.3747			
2660	1.3973			
2670	1.4178			
2680	1.4447			
2690	1.4665			
2700	1.4898			
2720	1.5057			
2730	1.5303			
2740	1.5603			
2750	1.6106			
2760	1.6279			
2770	1.6395			
2780	1.6581			
2790	1.6899			
2800	1.7285	.....	....	4331697
2810	1.7599			
2820	1.7793			
2830	1.8111			
2840	1.8553			
2850	1.8807			
2860	1.8936			
2870	1.9453			
2880	1.9881			
2890 (*m*)	.....	2880	95623	

(*m*) Broke in the middle in putting on strain. Gave warning by a slight crackling sound a few seconds before breaking, and broke gradually.

Fracture: Yellowish gray, with slight pinkish tinge, somewhat like brass alloy No. 612, but more yellow. Coarse granular structure, with radiated fibres near the edges. Slightly lustrous. Fractured section—trapezoidal.

11. RECORD OF TESTS BY TRANSVERSE STRESS.

Copper....55.00%
Tin 0.50%
Zinc.....44.50%

TRIPLE ALLOY OF COPPER, TIN AND ZINC.
Lab. No. 1001.

DIMENSIONS.		
Distance between Supports.	Breadth. b.	Depth. d.
22″	1.″	.979″

PROOF STRESSES.	DEFLECTION.	BREAKING LOAD.	
Absolute. P_1	Actual.	Absolute. P	Modulus. $R=\frac{3Pl}{2bd_2}$
3			
10	.0021		
20	.0051		
40	.0122		
80	.0417		
120	.0321		
160	.0417		
200	.0519		
10	.0024		
3	.0004		
200	.0520		
240	.0631		
280	.0734		
320	.0813		
360	.0899		
400	.1001		
10	0.0028		
3	.0008		
400	.0997		
440	.1102		
480	.1199		
520	.1300		
560	.1402		

11. RECORD OF TESTS BY TRANSVERSE STRESS.—(*Continued.*)

Copper....55.00%
Tin..... 0.50%
Zinc.....44.50%

TRIPLE ALLOY OF COPPER, TIN AND ZINC.
Lab. No. 1001.

DIMENSIONS.		
Distance between Supports.	Breadth. b.	Depth. d.
22″	1.″	.979″

PROOF STRESSES.	DEFLECTION.	BREAKING LOAD.	
Absolute. P_1	Actual.	Absolute. P	Modulus. $R=\frac{3Pl}{2bd_2}$
600	.1516		
10	.0046		
3	.0018		
600	1518		
640	.1623		
680	.1745		
720	.1881		
760	.2024		
800	.2164		
10	.0140		
3	.0119		
800	.2167		
840	.2296		
880	.2443		
1400			
3(*a*)	.3089		
10	.3097		
3	.3057		
. . ..	.....	2100	72308

(*a*.) No. 1001 (55 Cu. 0.5 Sn, 44.52 n.) The scale beam could not be raised by applying more pressure after 2 100 pounds was reached, This was due to the rapid bending of the bar, which, however, could not be broken until it was nicked with a saw on all sides. The casting was not very sound externally, and the corners were somewhat rounded, owing to the metal not having filled the mould completely. After 1400 lbs. was reached and applied, a test was made to determine the recovery from set with time. When balanced at 3 lbs. the micrometer read 0.3089″. After 20 minutes the scale beam balanced at 5½ lbs., and after 15 hrs. 45 minutes at 10 lbs. The reading of the micrometer was again taken, it being this time 0.3094″, showing a difference of .0005, which may be ascribed to the gradual recovery or springing back of the wooden frame of the machine after it was relieved from pressure. When the pressure of 5.5 lbs. was taken off and the scale beam again balanced at 3 lbs., a reading of 0.3057 was obtained, which indicates a recovery from set of 0.3094″—0.3057″=0.0037″ in 15¾ hours.

12. RECORD OF TESTS BY TENSION.

Copper, cast very hot. CAST COPPER.
Lab. No. 581A.

DIMENSIONS. Original and Final.	
Length. L, L′	Diameter H, H′
5″	.798

STRESSES.		PROOF LOAD PER SQUARE INCH AREA OF		BREAKING LOAD PER SQUARE INCH.		EXTENSION.
Proof.	Ultimate.	Original Section. P	Fractured Section. P′	Original Section. T.	Fractured Section. T′	Actual.
400						.0004
600						.0007
1000						.0011
2000						.0022
3000						.0025
4000						.0027
5000						.0026
6000						.0032
6800						.0083
7200						.0132
8000						.0358
8400						.0492
8800						.0642
9200						.0792
9600						.0942
9800						.1073
250						.0951
9800						.1082
10200						.1218
10600						.1408
11000						.1605
11400						.1794
11800						.2008
12200						.2191
12600						.2405
13000						.2626
14000						.3258
270						.3155
14000						.3270
14400						.3448
14600 (a)	14600	29200	34790	29200	34790	.3760

(a.) Broke while reading was being taken. Broke ¼ inch from "A" end. The fractured section distorted from circular form. Three diameters measured .737'' .725'' and .732.'' Fracture: fine, fibrous looking, radiated and compact. Strongest piece of copper yet tested.

13. RECORD OF TESTS BY TRANSVERSE STRESS.

CAST COPPER.

Copper, cast very hot.

Lab. No. 581.

DIMENSIONS.		
Distance between supports.	Breadth. b	Depth. d
22″	.990	.980

PROOF STRESSES.	DEFLECTION.	BREAKING LOAD.		MODULUS OF ELASTICITY.
Absolute. P_1	Actual.	Absolute. P	Modulus. $R=\frac{3Pl}{2bd^2}$	$E=\frac{Pl^3}{48\delta I}$
10	0.0033			
40	.0116	.....	.....	9851369
80	.0224	.....	.....	10203205
120	.0355	.....	.....	9657120
160	.0513	.....	.....	8910400
200	.0729	.....	.....	7837853
5	.0260			
240	.0964	.....	.....	7112607
280	.1280			
320	.1705	.....	.....	5361919
360	.2253			
400	.3079	.....	.....	3711460
5	.2040			
440	.4169			
480	.5565			
520	.7540	.....	.....	1970274
560	.9155			
600	1.1635			
5	1.0085			
600	1.2105			
640	1.37			
680	1.63			
720	1.93	.....	.....	1065786
760	2.23			
800	2.60			
820	2.83			
840	3.09			
860 (*a*)	3.49	.....	.....	720375
1150 (*b*)	5.74			
3000 (*c*)	8.00	3000	29848	

(*a*) The supports slipped. Placed the bar on cast iron fixed supports 20 inches apart, and (*b*) 1 150 lbs. gave it a further deflection of 2¼ inches. Moved the supports to 10 inches, and applied (*c*) 3 000 lbs., when bar broke, the total deflection being about 8 inches.

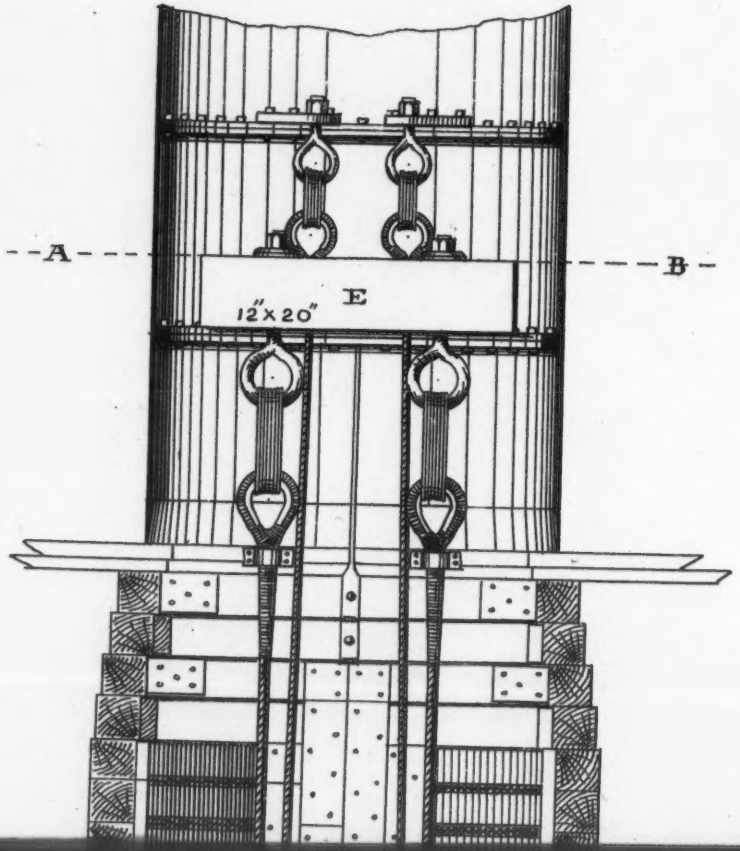
Fracture: Coarsely fibrous and radiate from centre of surface of fracture. Color: Dark red from superficial oxidation. Fibres interrupted and covered over with minute ridges, with sharp lines of separation.

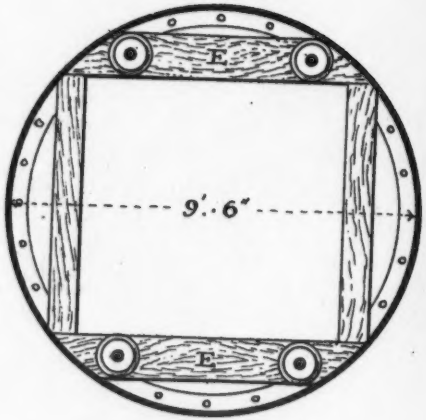
14. RECORD OF TESTS BY COMPRESSION.

Copper, cast very hot. CAST COPPER.

Lab. No. 581.

DIMENSIONS. Original and Final.		STRESSES.		PROOF LOAD Per Square Inch Area of Original Section. P	BREAKING LOAD Per Sq. Inch Original Section. T	COMPRESSION.
Length. L, L′	Diameter H, H′	Proof.	Ultimate.			Actual.
2″	.625	500	.....	.....	.....	.0026
.....	.....	1000	.....	.....	.....	.0046
.....	.....	2000	.....	.....	.....	.0079
.....	.....	3000	.....	.....	.....	.0109
.....	.....	4000	.....	.....	.....	.0143
.....	.....	5000	.....	.....	....	.0177
.....	.....	6000	.....	.....	.....	.0212
.....	.....	7000	.....	.....	.....	.0263
.....	.....	8000	.....	.....	.....	.0347
.....	.....	9000	.....	.....	.....	.0513
... .	.....	10000	.....	.....	.....	.0801
....	.....	11000	.....	.....	.....	.1187
.....	.....	12000	.....	.....	.....	.1619
.....	.....	13000	.....	.....	.....	.2053
.....	.....	14000	.....	.....	.....	.2508
.....	....	15000	.....	.....	.....	.2942
.....	.....	16000	.....	.....	....	.3373
.....	.....	17000	.....	.....	.....	.3378
.....	.....	18000	.....	.....	.....	.4722
.....	.....	19000	.....	.....	.....	.4688
.....	.....	20000	.....	.....	.....	.5100
... .	.....	21000	.....	.....	.....	.5594
.....	.....	22000	22000	71709	71709	.6415





SECTION ON A.B.

Fig. 2.

PLATE XLVI
TRANS. AM. SOC. CIV. ENG'RS
VOL. X. Nº CCXXIX
STAUFFER
ON SHAFT SINKING.

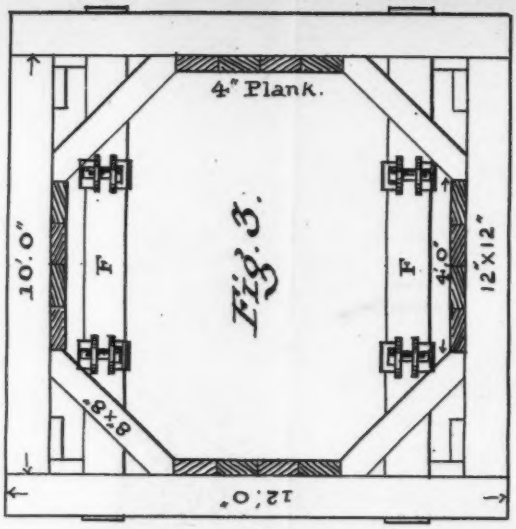


Fig. 3.

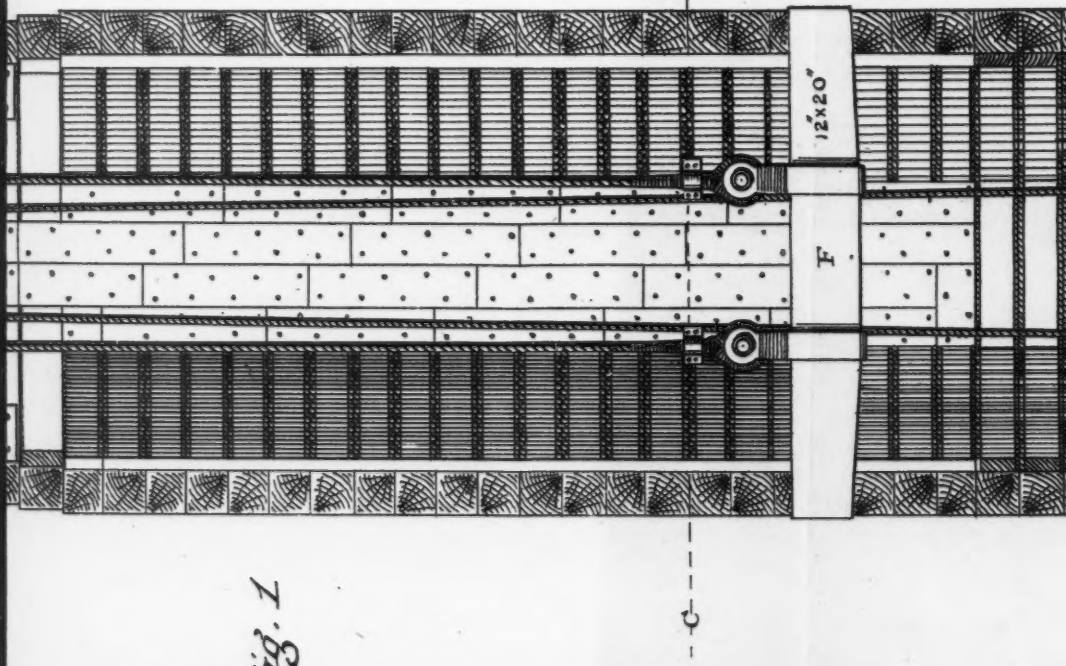
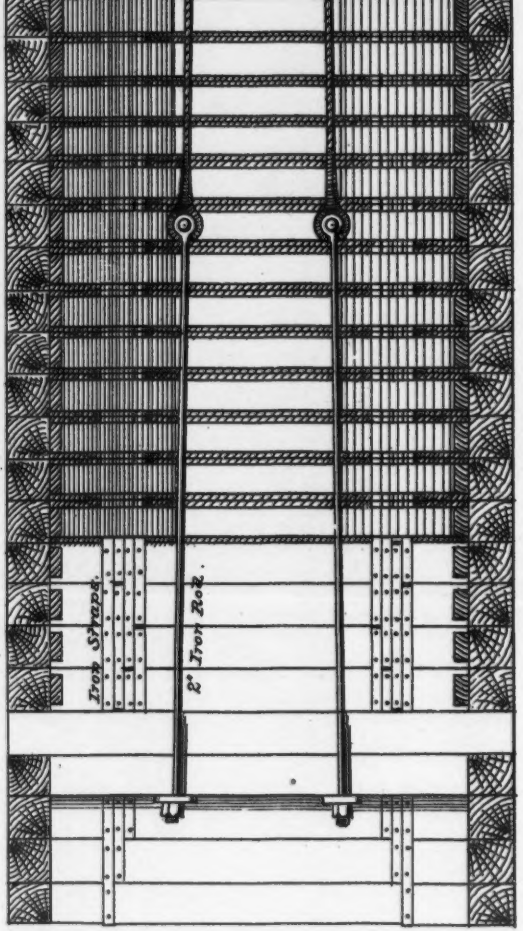
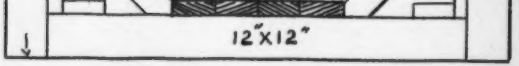


Fig. 1

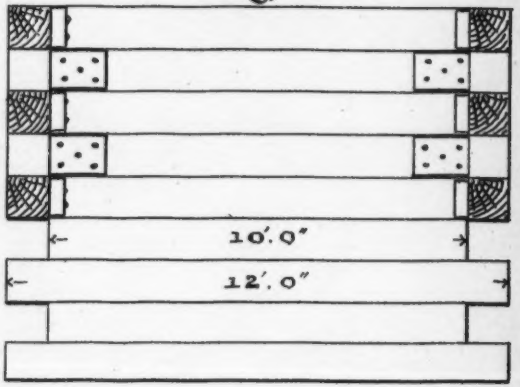


VERT. SECTION OF SHAFT.



SECTION ON C.D.

Fig. 4



SHAFT FRAMING.

SCALE OF FEET.